Under Secretary of Defense
(Acquisition, Technology and Logistics)

NASA Aeronautics Facilities Critical to DoD

Report to Congress

January 2007

Summary

In the Conference Report that accompanied H.R. 4200, the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, H.R. Rep. No. 108-767, p. 582, the conferees requested the Under Secretary of Defense for Acquisition, Technology and Logistics to identify and analyze aeronautics facilities managed by the National Aeronautics and Space Administration (NASA) that are considered by the Department to be critical to the accomplishment of defense missions. The Under Secretary of Defense invited the affected DoD Components to designate high-level representatives to be part of a team that would conduct the requisite analysis and identify the NASA aeronautics facilities that were critical to the accomplishment of defense missions. The team was chaired by the Principal Deputy Director of the DoD Test Resource Management Center, and consisted of representatives of the Military Departments, the Director, Defense Research and Engineering, the Missile Defense Agency, and the Director, Defense Systems. NASA also supported the effort by sending a senior representative to team meetings and providing information upon request.

The team began with a list of 86 NASA aeronautics facilities that warranted further analysis to determine whether they were critical to defense missions. The DoD Components were provided the opportunity to add NASA aeronautics facilities to the list being evaluated. Each facility was reviewed by the DoD Components, using a survey that assessed the facilities' role in supporting weapon system development activities, science and technology activities, and the long-range needs of the DoD. The review included wind tunnels and other types of aeronautics facilities. To ensure the survey results reflected a needs-based assessment, rather than a cost-based assessment, the team members operated under the assumption that the Congress would continue to appropriate the necessary funds to NASA to maintain and sustain any aeronautics facilities that were determined to be critical to DoD. Based on that assessment, and further analysis, the study team developed a list of NASA aeronautics facilities that were potentially critical to the DoD. The members were also provided with the guidance that, to be critical, a facility needed to be one that, if it were unavailable to DoD, posed an unacceptable risk to research, development, modernization and sustainment of the weapon systems supporting the defense mission. After completion of the survey forms, the team members reviewed the results, as well as an assessment of possible alternatives to the use of each facility that had been identified as potentially critical to the DoD during the survey process. The survey results were analyzed. The team members then arrived at a consensus as to which NASA aeronautics facilities were critical to DoD and why each of them was critical.

The team has identified 12 NASA aeronautics facilities as critical to the defense mission. They are listed below. Section VI of this report provides the basis for the determination that each of those facilities is critical to the DoD for weapon systems research, development, and test and evaluation. It includes a description of the salient features and the unique characteristics of each critical facility.

- Glenn Research Center 6 × 9 ft Icing Tunnel
- Langley Research Center 20 ft Vertical Spin Tunnel
- Ames Research Center Unitary 11 ft Transonic Tunnel
- Langley Research Center National Transonic Facility (NTF)
- Langley Research Center Transonic Dynamics Tunnel (TDT)
- Langley Research Center 8 ft High Temperature Tunnel (HTT)
- Ames Research Center Vertical Motion Simulator (VMS)
- Glenn Research Center Mechanical Drives Facility

- Glenn Research Center Turbine and Structural Seals Facilities
- Langley Research Center Impact Dynamics Research Facility (IDRF)
- Wallops Flight Facility Open Air Range
- Ames Research Center National Full-Scale Aerodynamics Complex (NFAC) (Owned by NASA, but managed by the Air Force)

I. Introduction

This study was the result of a request contained in the Conference Report to accompany H.R. 4200, the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, H. R. Report No. 108-767, p. 582. The conference report included the following language:

> *Department of Defense—National Aeronautics and Space Administration coordination*
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> The conferees note that in the areas of aeronautics and space research technology development, the Department of Defense and the National Aeronautics and Space Administration (NASA) must coordinate closely in order to ensure that the nation continues its global leadership in these technologies.
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> The conferees believe that as NASA evaluates its future plans for aeronautics, it is essential that the Department and NASA provide for the continued availability of unique wind tunnels and other research, test, and evaluation facilities and services critical to the development of military systems. The conferees direct the Under Secretary of Defense for Acquisition, Technology and Logistics to identify and analyze aeronautics facilities currently managed by NASA that are considered by the Department to be critical to the accomplishment of defense missions and to the maintenance of U.S. leadership in aeronautics.

To complete the task requested by the conferees, the Under Secretary of Defense (Acquisition, Technology and Logistics) [USD(AT&L)] directed the Test Resource Management Center (TRMC) to analyze the Department's long-term requirements for NASA aeronautics facilities and develop a recommended response to Congress. In a memorandum dated November 7, 2005, the USD(AT&L) formed a study team, led by the TRMC, to conduct a survey of the needs of the Department and to formulate the response to Congress. This report summarizes the methodology used over the course of the study as well as the results of the study activity.

This study focused on NASA's aeronautics facilities. The study team defined aeronautics as the study of the design and construction of air vehicles (aircraft, missiles, space vehicles) or other science and engineering that involves the study of air flow over objects. While wind tunnels are a significant component of the overall inventory of aeronautics facilities, it is important to recognize that this study encompassed a broad review of aeronautics facilities, to include other categories, such as propulsion test facilities, simulation facilities, and open-air ranges. It is also noteworthy that this study, unlike some previous efforts to address the DoD need for aeronautical facilities, explicitly sought to include the requirements of the science and technology (research) community along with those of the weapon system development community in determining which facilities were critical to the Department.

II. Background

Historic DoD Dependence on NASA Facilities

Historically, DoD has depended on NASA for aeronautical test facilities. From its founding in 1915 to World War II, NASA's predecessor, the National Advisory Committee for Aeronautics (NACA), provided national leadership in aeronautics research. It also constructed and maintained the required testing infrastructure. On the eve of World War II, additional test facilities were built to meet the wartime requirement for aeronautics research and for engineering development of combat aircraft. NACA contributed significantly to the war effort and provided the basis for many aeronautical advances. The close relationship between the U.S. military and NACA over this period was evident in that the Advisory Committee that led NACA included representatives from the War Department and the Navy Department. Prior to World War II, NACA's research had both military and civil applications. During the war, its work was almost exclusively military, focusing more on solving specific problems with aircraft design than on advancing aeronautical knowledge.

After the war, aeronautics continued to advance rapidly, with the introduction of turbojet engines and the advent of transonic and supersonic flight. In 1947, the newly established independent U.S. Air Force, motivated by significant aeronautical advances that were observed in German systems during the war, requested the construction of an engineering and development center that provided the military with large major test facilities that were focused on obtaining data during the development of aeronautical systems. In 1949, in reaction to the nation's technological needs, Congress enacted Public Law 81-415[1], under which the Federal government completed a national plan of facility construction. The plan did two things; (1) it added major wind tunnels at NACA Research Centers [Langley, Lewis (subsequently renamed Glenn), and Ames), and (2) constructed the Air Force's Air Engineering Development Center [subsequently renamed Arnold Engineering Development Center (AEDC)] in Tullahoma, Tennessee. Those new facilities became available for use in the early 1950s.

In the 1960s, NASA and DoD identified the requirement for a new set of aeronautical test facilities as essential to advancing the nation's aeronautical progress. The solution was to construct the needed facilities at several locations with some built by NASA and some built by DoD. For example, the Air Force built the Aeropropulsion Systems Test Facility at AEDC beginning in 1977 and it reached full operation in 1985. The requirement for an advanced high Reynolds number test facility was satisfied when the National Transonic Facility was constructed at NASA's Langley Research Center and became operational in 1983. Thus, the complementary nature of the "federal test infrastructure" was confirmed. The interagency dependency continues today, and has been strengthened during recent interagency studies and through interagency cooperation.

Studies of NASA-DoD Aeronautics Facilities

Since the early 1990s, a number of studies were conducted on the subject of the Federal Government's aeronautics testing facilities. Those studies had a number of objectives. The majority focused on approaches to increasing the efficiency of the combined NASA and DoD test infrastructure, reducing the overall costs, increasing cooperation between the facilities' owning or operating organizations, or identifying the technology areas where investments were necessary. While limited

[1] Public Law 81-415, The Unitary Wind Tunnel Plan Act of 1949 and the Air Engineering Development Center Act of 1949. Currently Title 50 U.S.C. Sections 511 through 524.

progress was made in pursuing additional investments in facility advancements or new facilities, substantial progress was made in identifying facilities for closure and increasing interagency cooperation and communication.

Many studies performed during that period are helpful in determining which NASA aeronautics facilities are important to the performance of the DoD mission. Two such studies are particularly useful, namely the DoD Aeronautical Test Facilities Assessment (conducted in 1996-1997) and the congressionally directed RAND study of NASA wind tunnels and propulsion test facilities (conducted in 2002-2003). Among other things, the DoD Aeronautical Test Facilities Assessment reviewed forecasts for future defense systems and considered their respective testing needs. The study team examined the suite of major NASA and DoD wind tunnels and divided the list into the categories of core and non-core facilities. The study team report identifies core facilities as the "minimum essential government facilities for each type required to support weapons system development." The RAND study attempted to identify the need for the various NASA facilities, surveyed both industry and DoD practitioners, and identified those NASA aeronautics facilities that had advocates in either industry or defense organizations.

Recent Facility Closures

Prior to 1990, the aeronautics infrastructure of the DoD and NASA had considerable redundancy. The wind tunnels were constructed in geographical proximity to the NASA research organizations that would be the principal users. In addition, the relatively large number of aeronautical development and research programs underway resulted in the need for similar facilities to provide the capacity to conduct testing for multiple programs. The major DoD facilities at AEDC focused on supporting DoD development programs, while NASA facilities supported NASA aeronautical research as well as DoD development programs and development programs of the U.S. commercial aircraft industry.

NASA and DoD entered the 1990s, with a large suite of wind tunnels and propulsion test facilities. In 1993, a study of the NASA-DoD wind tunnels identified 60 major wind tunnels (some wind tunnels contained more than one test section, so the total was derived by counting each test section as a separate facility). By 1997, that number had decreased to 39, or a decrease of 35 percent. In 2006, the number had declined to 30, half of the major wind tunnel test sections that NASA and DoD were operating 13 years before. The number of major wind tunnels operated by NASA and DoD during these years is shown in Table 1. The decrease in the number of government wind tunnels resulted in less duplication and reduced capacity, which, in turn, increased the importance of maintaining the remaining facilities.

Table 1. Number of Major Government Wind Tunnels in 1993, 1997, and 2006

	1993	1997	2006
DoD	21	14	14
NASA	39	25	16

III. Study Approach

Review of Previous Studies

In February 2005, in response to the conferees' request, the Director of the TRMC reviewed recent studies and prepared a proposed response to the armed services committees containing a list of NASA aeronautics facilities that could be considered "core" facilities for the DoD. The list of facilities was determined largely on the basis of the 1997 DoD Aeronautical Test Facilities Assessment [1] and the RAND Corporation report published in 2004 [2] and [3]. Core facilities were defined as the minimum essential set of facilities required to support DoD weapon system development. The draft response focused solely on major facilities, using the same criteria as the 1997 Aeronautical Test Facilities Assessment.

The Director of the TRMC requested the DoD Components to review the proposed response. The review resulted in the decision to pursue a more thorough and up-to-date study in which DoD would systematically look at all needed aeronautical test capabilities and consider the full range of alternatives for specific critical capabilities. The expanded study would need to clearly define the term "critical" in order to establish the criteria under which critical facilities are identified.[2] The study was also to consider the requirements of the DoD science and technology (research) community.

Approach to Determining Critical Facilities

Guided by comments that supported a more comprehensive approach and a more current analysis, the TRMC developed a plan for a DoD study team to conduct an assessment of the Department's requirements for NASA aeronautics facilities and analyze the results. The expanded TRMC plan called for participation by all affected DoD Components. It provided for the inclusion of both the research (science and technology) and weapon system development communities. Finally, the new plan entailed assessing NASA aeronautics facilities from a Fiscal Year 2006 perspective rather than relying on an assessment that was completed nearly a decade ago. The TRMC then asked the USD(AT&L) to establish a study team that collectively contained personnel, with the requisite expertise, from the appropriate organizations, to gather the relevant data and perform the analyses necessary to support the response to the Congress.

Formation of Study Team

The USD(AT&L) invited the Military Departments; the Director, Defense Research and Engineering; the Assistant to the Secretary of Defense (Nuclear, Chemical and Biological Defense Programs); the Director, Missile Defense Agency; and the Director, Defense Systems to each designate a flag officer, or a member of the Senior Executive Service to represent them on the study team. With one exception, all invitees designated a representative to the DoD study team. The Office of the Assistant to the Secretary of Defense (Nuclear, Chemical and Biological Defense Programs) declined to participate because it lacked a stake in the subject matter. However, that office did provide advice to the study team.

[2] The study team agreed that, for purposes of this study, a critical facility is a NASA aeronautics facility that, if not available to DoD, poses on unacceptable risk to research (i.e., science and technology), development, modernization, and sustainment of the weapon systems supporting the defense mission. Risk may be an expression of cost, security, or time. The manner in which that definition was employed by the study team is discussed under the heading "Survey Methodology" on pages 6 and 7 of this report.

To provide an effective liaison and ensure that the study team's expectations were realistic, NASA was invited to send a representative to study team meetings. AEDC was engaged to assist by providing technical information and analyses. AEDC was also invited to send a representative to team meetings.

The study team was chaired by the Principal Deputy Director, Test Resource Management Center, and it held its first meeting on December 13, 2005.

Survey Methodology

In advance of the first study team meeting, the TRMC, with support from the Institute for Defense Analyses and the AEDC, reviewed information about the various NASA aeronautics facilities, identified those facilities with the potential to be designated as critical to the accomplishment of the defense mission, and drafted a facility survey form to capture the information that was important to ascertaining any given facility's criticality. Instructions were prepared to provide uniform guidance to anyone completing the survey forms, identifying the type of information expected in response to each item on the survey.

A list of 86 NASA aeronautics facilities was developed, with the intent of identifying those facilities that warranted analysis to determine if they were critical to the defense mission. Identification and capability information was added to the 86 survey forms prior to distribution to the study team members.

The remaining items on the survey forms were intended for completion by the DoD Components. The first series of questions was designed for weapon system development activities, requesting them to provide information about past, current, and projected future utilization of the particular NASA aeronautics facility. That series concluded with questions about how the facility was critical to the defense mission and what the DoD Component would do if the facility became unavailable. A parallel set of questions was directed to DoD science and technology activities. Then, the respondents were asked to identify any military capabilities or concepts that the facility would be required to support in terms of long-range (beyond Fiscal Year 2012) needs of the Department of Defense.

The survey concluded by asking respondents to identify any unique national expertise resident at the NASA facility that was required in support of the DoD mission as well as any additional information that the respondents might consider relevant. Finally, each respondent activity was asked to provide a DoD Component point of contact who could respond to questions about the entries that appear on the form.

Before the survey forms were distributed to the DoD Components for completion, the draft forms and the accompanying instructions were reviewed by the representatives of the DoD Components at the first study team meeting. At that time, the representatives were given a briefing on what was expected and afforded an opportunity to comment on the survey instrument and the instructions. The survey was modified somewhat, and the instructions were clarified in response to comments provided by the DoD Components. The finalized forms were then distributed to the DoD Components.

The DoD Components surveyed their organizations and completed survey forms for those NASA aeronautics facilities that were important to their science and technology efforts and development programs. The completed forms were then used to determine the Component's position on the criticality of the facility.

The scope of the survey was self-limiting in that the respondents were asked to confine their responses to information that helped in identifying those NASA facilities critical to the accomplishment of the defense mission. The DoD Components were advised that their responses should not include an effort to identify facilities that are critical "to the maintenance of U.S. leadership in aeronautics." The rationale for this assumption was that the maintenance of U.S. leadership in aeronautics is an issue that involves Government activities outside the DoD as well as industry and academia. The DoD is not in a position to speak for those other organizations.

In the event that a facility that is critical to the DoD was inadvertently omitted from the list of 86 NASA aeronautics facilities that was used to initiate the survey, the DoD Components were advised to complete an additional form, so the facility could be considered in the review. Similarly, if the DoD Components noticed that any characteristics or features of the respective NASA aeronautics facilities had been omitted from the forms that were prepared, they were invited to supply the additional information to make the submittals more complete. As the DoD Components completed their portions of the facility survey forms, some of them requested input from NASA and the NASA centers cooperated.

Significance of Long-term Needs

As indicated above, the survey form asked particular questions for the purpose of identifying the long-term needs of the Department. It was important to identify those needs because, in recent years, changing military requirements and fewer new aeronautical program starts have caused the activity level in the U.S. aerospace industry to reach a low level. Consequently, facilities that were built for a continuous workload are now used infrequently. Sometimes, years may pass between high-priority testing in certain facilities, causing the facility to be used intermittently or mothballed between use periods.

Determining national needs in this environment requires a long-term examination of test capabilities that are required now and in the future. A short-term examination of planned or scheduled usage is of limited value and may produce an invalid perspective on the needs for aeronautics facilities. The test capability necessary for the United States to maintain its aeronautical defense systems can be determined by looking at the range of aeronautics capabilities that are likely to be tested over the long term, identifying the testing envelopes and capability ranges required, and then determining which facilities have the necessary capabilities.

Assumptions

The entire study was predicated on the assumption that the Congress would continue to appropriate the necessary funds to NASA to maintain and sustain any aeronautics facilities that were designated as critical to the DoD. The rationale for this assumption was that this survey was intended to be a needs-based, vice a cost-based, assessment. The needs in this case were for the capabilities that are resident in specific NASA aeronautics facilities and the intellectual capital associated with those facilities.

While the survey instrument included questions about how any given NASA aeronautics facility is critical to the defense mission, the congressional tasking did not provide a definition of the word "critical." Therefore, in order to guide survey respondents, the instructions explained that a critical facility was a NASA aeronautics facility that, if not available to DoD, posed an unacceptable risk to research (i.e., science and technology), development, modernization, and sustainment of the weapon systems supporting the defense mission. The instructions stated that the risk may be an expression of cost, security, or time.

Survey Results

The DoD Components completed the survey and submitted the results for integration and review. After a tentative list of critical facilities was reviewed by the study team, additional discussion led to the refinement of that list. The detailed analyses discussed in the next sections were performed on the facilities identified in Table 2.

Table 2. NASA Aeronautics Facilities identified as Critical to DoD

	Location	Type	Facility
1	Glenn	Subsonic Wind Tunnel	6 × 9 ft Icing Tunnel
2	Langley	Subsonic Wind Tunnel	20 ft Vertical Spin Tunnel
3	Ames	Transonic Wind Tunnel	Unitary 11 ft Transonic Tunnel
4	Langley	Transonic Wind Tunnel	National Transonic Facility (NTF)
5	Langley	Transonic Wind Tunnel	Transonic Dynamics Tunnel (TDT)
6	Langley	Hypersonic Wind Tunnel	8 ft High Temperature Tunnel (HTT)
7	Ames	Other Facilities	Vertical Motion Simulator (VMS)
8	Glenn	Other Facilities	Mechanical Drives Facility
9	Glenn	Other Facilities	Turbine and Structural Seals Facilities
10	Langley	Other Facilities	Impact Dynamics Research Facility (IDRF)
11	Wallops	Other Facilities	Open Air Range
12	Ames	NASA-Owned, DoD-Operated Facility	National Full-Scale Aerodynamics Complex (NFAC)

The detailed rationale for designating these facilities as critical is contained in section VI of this report

Analytical Process

To complete the analysis, two additional steps were performed to ensure the study team had accurate and complete information from which to make its final decision on the designation of which NASA facilities were critical. The two major steps in this process were the development of two documents to be used by the study team. The two documents were the Independent Review and Alternative Assessment the DoD Criticality Rationale, and they were prepared for each of the facilities that were tentatively designated as critical.

Independent Review and Alternative Assessment

An Independent Review and Alternative Assessment was prepared for each tentatively designated critical facility by the AEDC staff and their supporting contractor. The purpose of these documents was to integrate the DoD Components' responses to the survey, verify technical accuracy of the survey descriptions, and to identify and analyze the various alternatives that exist for each "critical" facility. The Independent Review and Alternative Assessment included the following sections: (1) Overview of each "critical" facility, (2) Major characteristics and unique features, (3) Types of testing conducted, (4) Technical and other factors that provide the DoD rationale for identifying the facility as "critical", and (5) Identification and analysis of alternatives available to DoD Components if the "critical" NASA facility is no longer available. The information within the Independent Review and Alternative Assessment was drawn from the survey responses and additional information provided/obtained by AEDC.

DoD Criticality Rationale

The DoD Criticality Rationale was prepared by the Institute for Defense Analyses (IDA). It summarizes, in narrative format, the information on each facility identified as critical, focusing on clearly stating the rationale for "criticality". The document included the following content: (1) comprehensive narrative overview of each "critical" facility, (2) major characteristics and unique features, (3) the significance of the facility for both science and technology and for weapon system development, (4) selected alternatives to use of the facility, and (5) the complete rationale for designating the facility "critical". The sources for the information in the DoD Criticality Rationale were the survey responses from DoD Components, plus additional information, such as alternatives identified by AEDC.

IV. Other Considerations

There are additional considerations that must be taken into account when evaluating the importance of aeronautics facilities beyond the short-term need for the facility in order to conduct testing.

Role of Workforce in Test Capability and Capacity

The workforce associated with a particular facility can be important when reviewing the long-term need for a facility. The workforce in many cases includes one or more shifts of competent, trained personnel who operate the facility and obtain the necessary data and, perhaps, process the data into useable format for the researchers or test customers. The workforce may also include a cadre of experts in the particular work performed in the facility. As an example, the Glenn Research Center Icing Research Tunnel is associated with a workforce to plan, prepare and operate the tunnel during testing, as well as a group of nationally recognized experts on the icing of aircraft. The importance and criticality of the facility to the defense mission depends on both aspects of the facility, the physical capability of the icing wind tunnel and the technical knowledge and experience of the associated workforce.

The capacity of the facility may also be determined by the assigned workforce. If the owning agency has forecasted the number of hours of usage and plans to operate the facility for a single shift, five days a week, and has contracted for the contractor support required for such a schedule, it may be difficult to increase the number of shifts without sufficient advance notice to permit the requisite increase of the contracted workforce. Thus, while increasing the shifts of operation may be possible over a longer term, the short-term increase may be very difficult. Similarly, when assessing the capacity of the various facilities, it is necessary to consider what capacity would be available with the planned work shift arrangement and what capacity could ultimately be available, if the workforce were not a constraint. In the final analysis, in order to realize the full capability of an aeronautics facility and allow it to operate at the desired capacity, it is essential to maintain a competent workforce at that facility.

Need for Back-up Facilities

There are at least two situations in which the need for backup facilities can be considered. The first is the capacity situation where the workload is high enough that one facility is normally not capable of providing the number of hours of usage required to accomplish the combined workload of DoD, NASA, and the U.S. aerospace industry. For example, the workload requirements for large transonic wind tunnels are usually so substantial that both the AEDC 16-T wind tunnel and the Ames 11-foot wind tunnel are normally considered as necessary to satisfy the total combined U.S. workload. The second situation arises when a given facility may experience a lengthy period of unplanned or planned downtime and a second facility is considered necessary to provide continuity since it would be undesirable or too costly to defer the workload until the primary facility becomes available again. This downtime could be the result of a number of events including the following:

- Failure. Major facilities of the types being discussed have the potential for failures that would require an extensive period of time for repair. The large, rotating, one-of-a-kind machinery in many of these facilities has a very low probability of failure when it is properly maintained, but if a failure were to occur, there could be a significant period of time during which the facility would not be available for testing or research.
- Natural catastrophe or accidental damage. A similar situation could occur if a facility was damaged by either natural causes (such as a tornado, earthquake, etc.) or an accident (such as the unintentional separation of a piece of a model during a wind tunnel test). Recovery from significant damage could require a substantial period of time.
- Downtime for modification. Major upgrades and modernization programs to the current facilities, while less frequent under current financial conditions, are still possible. An alternate facility may be necessary to perform the required workload during the resulting downtime.

Currently, only one NASA aeronautics facility identified as critical to the Department of Defense in this report can be categorized as a backup facility. That is the 11-foot transonic wind tunnel at Ames Research Center, and it is included due to the considerable amount of DoD transonic workload that frequently exceeds the capacity of the DoD's own large transonic wind tunnel, AEDC's 16T transonic wind tunnel.

Consequently, it should be recognized, that while not designated as "critical," there are other aeronautics facilities that are managed by NASA that serve as potential backups to DoD's own facilities and are therefore important to the accomplishment of the DoD mission. These additional NASA facilities are important to DoD as back-ups in case a primary DoD facility or a critical NASA facility is not available due to failure, damage, or downtime for modification.

V. Interagency Coordination

NASA and DoD have a longstanding relationship in matters involving the federal aeronautical test infrastructure. As two separate federal agencies, they recognize that, collectively, they own and control a number of significant national assets that provide the capability for aeronautical research, development, test and evaluation. Consequently, the practice of consulting and coordinating across agency lines will continue, and they will rely on one another to help sustain the nation's aeronautical test capabilities.

VI. NASA Facilities Critical to DoD

The following sections provide the rationale for the 12 NASA aeronautics facilities determined by the study team to be critical to the Department of Defense. Each section summarizes the technical characteristics, unique features, and possible alternatives that are available for one of the 12 facilities.

6 × 9-foot Icing Research Tunnel, Glenn Research Center

The Icing Research Tunnel (IRT) is a wind tunnel with a 6 × 9 foot test section, capable of generating wind velocities from 50 to 390 miles per hour and temperatures from ambient to -25°F. It can produce super-cooled water droplets.

The IRT is used for investigating icing in subsonic flight, where test models and flight hardware need to be full scale to obtain valid heat-transfer data on anti-icing systems. Types of testing done at the IRT include phenomenology research, effects on flight, ice prevention systems, and flight certification. While its principal contribution is the development of de-icing systems, the IRT also contributes to defining the characteristics of ice particles that are shed into propulsion system inlets. The IRT is used by the DoD for weapon systems development.

The IRT is the largest and fastest icing facility in the United States. There is no other icing facility in the United States capable of supporting full-scale component tests on engine inlets, vehicle forebodies, and radomes. In addition, the IRT staff has extensive experience in facility support and the testing of ice protection systems.

The facility in the United States that comes closest to having similar capabilities is the Boeing Research Aerodynamic and Icing Tunnel (BRAIT) in Seattle, Washington. However, its test section is only half the size of the IRT, and its maximum airspeed is 25 percent less. Furthermore, it is primarily intended for the testing of Boeing products, and it is unlikely that Boeing will be favorably disposed to allowing competing companies to use the facility. Although two other U.S. alternatives exist, they are both significantly smaller than the BRAIT and should only be considered if the BRAIT were unavailable. Overseas, the CIRA (Italian Aerospace Research Center) Icing Wind Tunnel (IWT), which is located in Capua, Italy, has the world's best icing capability. Its largest test section is 7.7 feet square, making it slightly larger than the IRT. It has a maximum speed capability of more than 500 miles per hour. However, the staff of CIRA's IWT is not as experienced as the staff of the IRT. Furthermore, it is a foreign facility, and it may pose security risks, particularly for the testing of stealth inlets and unmanned combat air systems.

For DoD, the IRT is a core facility that is critical to manned and unmanned aircraft and pilot survivability in severe icing conditions for all flight profiles. All the Military Departments have a potential need for the IRT to provide long-range support during system development, conduct credible large-scale examinations of icing phenomenology and ice protection systems, and generate the tools needed for ice protection systems in future aircraft designs.

20-foot Vertical Spin Tunnel (VST), Langley Research Center

The 20-foot Vertical Spin Tunnel is a closed-throat, continuous flow, vertical, annular return, wind tunnel. The test section is 20 feet in diameter by 25 feet high, and the velocity ranges from 0 to approximately 60 miles per hour. The control system allows rapid changes in fan speed.

The VST is used to investigate the spin characteristics of airplanes by testing free-spinning, dynamically-scaled models. It can be used to test aircraft models in the subsonic flight regime for spinning, tumbling, and other out-of-control situations. Spin recovery characteristics are studied by remotely actuating the aerodynamic controls of models to predetermined positions. It is used for the development of highly maneuverable aircraft (e.g., fighter, unmanned aerial vehicles, and future long-range strike aircraft), as well as forebody modifications of any fighter aircraft or payload traditionally requiring a spin-susceptibility test. Additionally, the facility is capable of spin chute sizing

The VST is the largest vertical tunnel in the world. Its test section was specially constructed for testing the spinning, tumbling, and free-falling characteristics of bodies.

If the VST were unavailable, two alternatives would be to conduct spin testing in the Vertical Wind Tunnel (VWT) at Wright-Patterson Air Force Base, Ohio or Bihrle's Large-Amplitude-Multi-Purpose (LAMP) Wind Tunnel in Germany. However, the VWT is 40% smaller in diameter than the VST while the LAMP is 50% smaller. The VST is a substantially larger facility and it can accommodate larger models and provides better simulation of flight Reynolds numbers. Larger models also allow more room for instrumentation and model configuration control to demonstrate advanced spin recovery techniques. Both the VWT and the LAMP have spin rigs, but they do not have a free-spin capability like the VST does, and free-spin testing is superior for determining spin susceptibility

Another alternative that could be pursued if the VST were unavailable is use of the Central Aerohydrodynamic Institute (Russian acronym TsAGI) T-105 wind tunnel at Zhukovsky Air Base, Russia. The T-105 is about 25 % smaller in diameter than the VST, although it is capable of speeds that are about 54 miles per hour higher than the VST. While the T-105 is the largest worldwide alternative to the VST, security issues are a potential risk that needs to be evaluated on the basis of the security requirements for any given test program.

The VST is critical to the accomplishment of the defense mission because it is the largest spin tunnel in the world, the only free-spin tunnel in the United States, and essential to determining certain aerodynamic characteristics of the highly maneuverable aircraft that are developed and modified by DoD.

Unitary 11-Foot Transonic Wind Tunnel, Ames Research Center

The 11-Foot Transonic Wind Tunnel is the 11 × 11-foot test section of the Unitary Plan Wind Tunnel at the Ames Research Center. It is a continuous flow, variable pressure transonic wind tunnel. The velocity ranges from Mach 0.2 to 1.5; the unit Reynolds number range is from 300,000 to 9,600,000 per foot, and the total pressure range is from 3.0 to 32 pounds per square inch absolute. The other active major component of the Unitary Plan Wind Tunnel is a 9 × 7-foot supersonic test section, and test models are interchangeable between the two test sections, which provides for testing up to a Mach number of 2.5 across a wide range of conditions.

Because of the high volume of testing that is required in the transonic flight regime, the DoD and its contractors use the 11-Foot Transonic Wind Tunnel for additional capacity and as a back-up to the AEDC 16T. The 16T has a larger test section and a slightly lower rated pressure shell. Both tunnels are configurable for half-model testing. However, while high-pressure air is available to drive engine simulators, ejectors, and plume simulation tests in the 11-Foot, it lacks the capability to do propulsion system exhaust scavenging, which is inherent in the 16T.

What makes the 11-Foot Transonic Wind Tunnel comparable to the 16T is the combination of test section size, Mach number range, altitude simulation, optical access (through large windows), pressure sensitive paint capability, productivity, and excellent flow quality.

The 16T at AEDC is the obvious alternative to the 11-Foot Transonic Wind Tunnel. However, from a DoD perspective, the 11-foot tunnel is the preferred backup to the 16T. Some smaller tunnels may be used as alternates to the 16T if the 11-Foot Transonic Tunnel were unavailable. The National Transonic Facility at the Langley Research Center, for example, with its slightly smaller test section, could support some DoD programs where smaller size and lower Mach numbers are not significant issues. Another alternative is the Calspan 8-foot tunnel in Buffalo, New York. The Calspan tunnel, however, has a smaller test section size, reduced Mach number range, and poorer flow quality than the 11-Foot Transonic Wind

Tunnel. It has a Captive Trajectory System, which the 11-foot tunnel does not. The Aircraft Research Association (ARA) transonic wind tunnel in Bedford, United Kingdom, has productivity and flow quality that are similar to the 11-foot tunnel. It is capable of supporting some DoD programs where smaller size and lower Reynolds numbers are not significant issues.

The transonic regime is both complex and critical to weapon systems development. Due to the volume of workload in that test regime, the DoD needs to maintain access to more than one large-scale transonic wind tunnel. That way, the Department can ensure that there is enough capacity available to accomplish its workload, even during periods in which one facility or the other is closed for maintenance or modernization. The combination of test article size, Mach number, and altitude range available in the 11-Foot Transonic Wind Tunnel is critical to DoD transonic testing requirements for aerodynamic simulation, especially for the testing of long-range aircraft systems. It provides critical capacity and back-up for the AEDC 16T tunnel in the transonic testing of high performance aircraft and missiles. It is the principal alternative to the 16T for both classified and unclassified tests that do not involve propulsion or use of a captive trajectory system.

National Transonic Facility (NTF), Langley Research Center

The National Transonic Facility (NTF) is a high pressure, cryogenic, closed-circuit wind tunnel with an 8.2- by 8.2-foot test section. The tunnel has a speed range from Mach 0.1 to 1.2 and a unit Reynolds number range from 4 million to 145 million per foot. The NTF can operate in three modes with different test gases to provide a wide range of test conditions. The three modes are: (1) an air mode with air as the test gas, (2) a cryogenic mode with nitrogen as the test gas, and (3) a mixed mode which uses air, augmented with liquid nitrogen (LN2) cooling.

The NTF is used to support stability and control, cruise performance, stall buffet onset, and configuration aerodynamics validation testing of both half- and full-span models in the transonic flight regime, up to a Mach number of 1.2. The cryogenic facility has the ability to match the high flight Reynolds numbers that cannot be achieved in conventional wind tunnels that operate at ambient temperature. A further advantage of the cryogenic concept is that Mach number, Reynolds number, and dynamic pressure can each be varied, while keeping the others constant, so the effects can be studied independently. If high Reynolds number testing at a Mach number below 0.5 in air at up to 8 atmospheres is desired, no other facility has the test capability of the NTF.

In the past, DoD has used the NTF for science and technology (S&T) testing of high lift aerodynamics. DoD has also used the NTF to support unmanned aerial vehicle (UAV) concepts. The Joint Strike Fighter (JSF) program has tentative plans for use of the NTF.

If the NTF was not available, the only alternative wind tunnel for testing at matching high Reynolds numbers is the European Transonic Wind (ETW) Tunnel located in Koln, Germany. The ETW, however, is smaller in size than the NTF and has a pressure shell rated approximately half that of the NTF. Both tunnels are cryogenically cooled and operate at comparable temperature ranges and test Reynolds number effects over the transonic flight regime. More conventional tests (i.e., at lower Reynolds number in air) are better accommodated within the United States in other large transonic wind tunnels such as the AEDC 16T and the Ames Research Center’s 11-foot transonic wind tunnel.

The NTF is vital to determining scaling effects for transport aircraft, bombers, and other long-range vehicles. While modeling and simulation (M&S) tools exist to help in the design effort from a conceptual perspective, extrapolation of Reynolds number effects to flight conditions poses increased risk of inaccurate prediction of flight characteristics. To achieve the necessary M&S fidelity for vehicle design and performance, the M&S tools must be calibrated using physical testing under high Reynolds numbers. This testing is the primary purpose of the NTF.

Transonic Dynamics Tunnel (TDT), Langley Research Center

The Transonic Dynamics Tunnel (TDT) is dedicated to investigating flutter problems in the subsonic and transonic flight regimes. The TDT is a continuous-flow pressure tunnel with a 16-foot square, slotted-wall test section capable of operating at speeds up to Mach 0.5 in air and Mach 1.2 in heavy-gas—achieving Reynolds numbers of about 3 million per foot in air and 10 million per foot in tetrafluoroethane gas (R-134a). Testing in a heavy gas (such as R-134a) allows improved model-to-full-scale similitude, higher Reynolds numbers, easier fabrication of scaled models, reduced tunnel power requirements, and—in the case of rotary-wing models—reduced model power requirements. The combination of heavy-gas and variable operating density permit the simulation of atmospheric conditions ranging from sea-level to nearly 80,000 foot (density altitude).

The TDT offers an air-stream oscillation system for the study of gust effects on both fixed- and rotary-wing aircraft. Unique features of the TDT include several safety systems (test section bypass valves, a main drive catch screen, and high-speed video systems) that prevent damage to the tunnel. These features make the TDT ideally suited to testing aeroelastically scaled models for stability, loads, and vibration. In addition to identifying the flutter characteristics in new aircraft designs, the TDT is also used to study active controls technologies for both fixed- and rotary-wing configurations, determine the effects of ground-wind loads on launch vehicles, investigate other aero-elastic phenomena (such as fixed-wing buffet and divergence), and provide data to support computational aeroelasticity and computational fluid dynamics (CFD) code development and validation. There is no other facility in the world of comparable size that is capable of replicating the speed and altitude capability of the TDT.

A wide variety of DoD fixed-wing aircraft, rotary-wing aircraft, and launch vehicle programs have used the TDT for system development including the F/A-18E/F, the F-22, the F-117, the Joint Strike Fighter (JSF), the V-22, and the Delta III launch vehicle. Several classified tests have been conducted in this facility. DoD has also used the TDT for a number of science and technology programs including the Defense Advanced Research Projects Agency (DARPA) morphing aircraft structures programs. In the future, the TDT may be used by the V-22, F-22, JSF, and the Joint Heavy Lift (JHL) programs.

The types of testing performed in the TDT are not possible in any other single tunnel; however, some dynamic tests can be performed in other transonic tunnels—provided the model is large enough and adequately scaled to accommodate the necessary features (such as stiffness, mass distribution, transport time, and other viscous effects). Testing in air requires much more expensive models that are substantially more difficult to construct. In addition, these types of tests pose the potential risk for damage to the wind tunnel if the model experiences structural damage and breaks apart. Without the safety features that are built into the TDT, other major tunnels are unlikely to be used for these tests. Therefore, facilities other than the TDT are much less desirable alternatives because of limitations on test section size, speed range, test article cost, and the ability to prevent catastrophic flutter events.

The TDT is essential for DoD testing for both flutter clearance and structural aeroelasticity—there is no other equivalent facility for conducting such testing. The loss of the TDT would limit the ability of the DoD to advance the state of the art for future heavy lift rotorcraft design concepts. Further, *any* future aircraft (e.g., advanced fighter, transport, or bomber) is potentially susceptible to aeroelastic and flutter problems. Without the TDT, there would be an unacceptable risk to achieving advancements required to support future heavy lift rotorcraft designs. It is estimated that alternative approaches to testing in the TDT would result in slowing the pace of large tilt-rotor efforts by 3-5 years. Without the TDT, development times would increase and actual flight hours would have to be substituted—both of which contribute to increased cost.

8-Foot High Temperature Tunnel (HTT), Langley Research Center

The 8-foot High Temperature Tunnel (HTT) is used by DoD for thermal protection systems testing, aerothermal loads definition, and hypersonic air-breathing propulsion system testing. The HTT has an 8-ft diameter, open-jet test section. Its blow-down-to-atmosphere vitiated air supply system simulates discrete flight Mach numbers of 4, 5, and 7 at altitudes from 50,000 to 120, 000 feet with stable test conditions provided for up to 60 seconds. The HTT also has a radiant heater system to simulate heating during ascent or descent and provides the capability to simulate flight enthalpy flow for propulsion, material, and thermal testing on large models.

In the recent past, the HTT has been used by DoD for the Hypersonic Flight (HyFly) program, and it is currently being used for hypersonic technology programs. This facility could also have relevance to the development of a hypersonic weapon system, hypersonic tactical missile, or space access vehicles.

One facility with capabilities similar to the HTT is the AEDC Aerodynamic Propulsion Test Unit (APTU). Upon completion of the upgrade currently in progress and scheduled to be finished by April 2007, the APTU will provide discrete (values to be determined by running various nozzles after the upgrade is completed) flight enthalpy test capabilities in the Mach 4 to 8 range for tactical scale missile systems and other aerothermal and aerodynamic tests. The available free-jet nozzles are expected to provide a uniform test medium flow field on the order of the same size as the HTT with a test duration that is approximately twice that of the HTT. Another facility, the NASA Glenn Research Center Hypersonic Tunnel Facility (HTF) at Plum Brook Station, is a possible alternative, but that facility has not operated for many years. The HTF is a free-jet test facility similar to the HTT and the upgraded APTU and could provide discrete Mach numbers of 5, 6, and 7. Because of its different test medium, the expense and problems associated with operating a graphite heater do not make the HTF a desirable facility for DoD. Several small commercial/university hypersonic research test facilities also exist across the country. Those facilities can provide up to Mach 8 test capability, but are very small relative to a full-size missile system. Run durations are also typically very short (on the order of 30 seconds). While these facilities are important for DoD research projects, they are inadequate as a DoD aeropropulsion test facility due to their small scale.

The HTT is currently providing DoD with hypersonic aerothermal and air-breathing propulsion environments for Mach 4 to 7 systems. After the APTU facility upgrade to Mach 8 is completed, the HTT will be the backup facility—providing additional capacity for the more capable APTU. Without the APTU capability, no testing alternative exists above Mach 4.0. Due to the amount of potential workload in this test regime, the DoD needs to maintain access to more than one hypersonic aerothermal and aerodynamic test environment to ensure there is sufficient capacity available to accomplish its workload requirements, even during periods when one facility or the other is closed for an extended period of time for maintenance, major repair, or modernization. Thus, the HTT is a needed facility. The impact of the loss of this facility could be high if hypersonic weapons development is required in the future.

Vertical Motion Simulator (VMS), Ames Research Center

The Vertical Motion Simulator (VMS) is a multi-configurable, real-time, piloted simulator that can generate solutions to cockpit configuration and aircraft responsiveness problems—facilitating design trade-offs early in the development or modification process. The VMS motion base has the largest vertical displacement of any simulator in the world, allowing the VMS to provide the highest level of motion fidelity available in the simulation community. Housed in a ten-story tower, the motion system allows the simulator to travel up to 60 feet vertically and 40 feet laterally for superior motion cues to the pilot. The simulator operates with three translational degrees of freedom (vertical, lateral, and longitudinal) and three rotational degrees of freedom (pitch, roll, and yaw), and can perform at maximum capability in all axes simultaneously.

The VMS includes a unique Interchangeable Cab (ICAB) system, a library of digital image generators, and a Virtual Laboratory. The ICAB system consists of five different interchangeable and completely customizable cabs that allow the VMS to simulate any type of vehicle, whether it is already in existence or in the conceptual phase. Each ICAB is customized, configured, and tested at a fixed-base development station, after which it is either used at one of the VMS fixed-base labs or moved onto the motion platform. The digital image generators provide full-color scenes on six channels, multiple eye view points, and a chase plane point-of-view. The VMS maintains a large inventory of customizable visual scenes with an in-house capability to design, develop, and modify the databases. Real-time aircraft status information can be displayed to both pilot and researcher through a wide variety of analog instruments and head-up, head-down, or helmet-mounted displays. The Virtual Laboratory (VLAB) is a software tool within the VMS complex that allows researchers at distant locations to participate in VMS simulations.

In the recent past, the VMS has been used by military helicopter programs, and is currently being used for upgrade activities for those programs.

There are no available alternative facilities in the United States with the capabilities of the VMS. Other commercial or government 6 degree-of-freedom (DOF) or 3 DOF simulators that are available, such as the CH-47 Chinook 6 DOF flight simulator and the Cockpit Motion Facility (CMF) at the NASA Langley Research Center have ranges of motion that are substantially less than that of the VMS. Additionally, most of the cockpits are not designed to be easily configurable. In Europe, the German National Aerospace Laboratory facility—called Generic Fighter Operations Research Cockpit Environment (GFORCE)—has a full 6 DOF motion capability, but translations are limited to about 5- by 7-ft—versus the 60- by 40-ft translation of the VMS. GFORCE does have a reconfigurable cockpit and flight dynamics with out-the-window scene generation including a simulated threat environment. The GFORCE may be suitable for applications where its limited translation motion range is adequate.

Considering the above, the only other viable alternative to the VMS that provides the necessary capability would be flight testing, which would increase the risk to cost, schedule, and safety to levels that would probably be unacceptable for most applications.

The VMS supports critical developmental risk reduction testing. It enhances aviation mission safety and increases efficiencies of flight test operations, resulting in increased probability of early identification of handling qualities issues and enhanced likelihood of implementing necessary corrective actions in a timely manner. If this facility were not available, flight safety may be adversely impacted, particularly during the early phases of testing, resulting in a significant impact to technical risk and schedule.

Mechanical Drives Facility (MDF), Glenn Research Center

The Mechanical Drives Facility (MDF) consists of a complete suite of drive system test rigs and laboratories. Rigs in the facility include, but are not limited to, a spiral bevel or face gear rig, a helicopter transmission test stand, an oil journal and thrust bearing rig, and a high-speed helical gear test rig. The facility contains a surface science and surface metrology laboratory.

The MDF test rigs are used to conduct basic and applied research on both mechanical components and systems, including experiments on individual gears and/or bearings to gain an in-depth understanding of various characteristics including wear, fatigue, and noise. The MDF is used to conduct research testing of gear-contact fatigue, gear-bending fatigue, the thermal behavior of high-speed gear systems, improvements in gear geometry, as well as gear noise and vibration. Tests can be conducted from the component level (gears or bearings) up to full-scale on helicopter main rotor transmission systems as well as on turbomachinery for air vehicles.

Component test rigs can simulate loading well beyond currently accepted design practices. Full-drive trains and systems can be tested at conditions up to 5,000 horsepower. Experiments can be tailored in the MDF for specific research projects or analysis of field problems in the areas of advanced gear, bearing, and transmission components; health and usage monitoring and diagnostics; thermal behavior of high-speed mechanical components; and lubrication technologies. As weapons systems continue to push technological limits, and their mechanical drive systems become increasingly complex and sophisticated, the test conditions in this facility can be adjusted to simulate operational conditions.

Only a limited number of mechanical testing capabilities are available in the United States. For helicopter propulsion system testing, the Helicopter Drives Facility (HDF) located at the Naval Air Systems Command, Patuxent River, MD allows the entire drive train of the helicopter (both the tail and main transmission) to be tested. This facility can test a variety of current and future helicopter propulsion systems. The helicopter transmission, excluding rotors, is installed in the HDF superstructure. Tests simulate flight loads applied by the craft's main rotor. Power for testing is provided by the aircraft's gas turbine engines and main and tail rotor power is absorbed by waterbrakes. The facility uses an 8,000 horsepower step-up (32:1 ratio) gearbox which converts the low speed/high torque main rotor shaft output to high speed/low torque output, allowing the use of waterbrake dynamometers for power absorption up to 8,000 horsepower and 325 RPM main rotor shaft speed. The main rotor shaft can be loaded by up to 3 waterbrakes which can be configured to match the main transmission power output. Near-term growth plans include an increase to 18,500 horsepower power absorption; reduction to system installation/removal time to two weeks; and an increase in size to accommodate CH-47, CH-53E and H-1 size systems. The central control room supports remote operation, control devices, instrumentation, measurement and monitoring of all parameters, real-time data recording and automated data acquisition. Recorded data is tailored to specific test requirements and may include engine input torques/speeds, main rotor and tail rotor output torques/speeds, vibrations, and critical system temperatures and pressures.

For other applications, alternatives would be to either go to contractors, such as helicopter and gear manufacturers, that would construct facilities to meet military requirements, or to construct facilities at universities and use available staff. Although the individual capability of each test rig in the MDF may then be available at another facility, it would require multiple locations to duplicate the full physical capability of this facility. The costs and the complexity of coordination would increase if multiple facilities were used, but the loss of the cohesive intellectual knowledge that is available when resident experts work together is the greatest concern.

The MDF has many unique test capabilities that are not currently available within industry or academia. The MDF plays a vital role in developing the analytical tools to model mechanical drives and components, and that is essential to drive system development. Those analytical tools then must be validated, and their performance calibrated, by physical testing. The technologies that are developed in the MDF affect the weight, range, and mission duration of vehicle systems, as well as their acquisition and life-cycle costs. The MDF is critical to the DoD because it is capable of supporting a broad spectrum of drive-train research and development needs, including those for unmanned aerial vehicles. Those needs and technologies are applicable and transferable to ground vehicle transmission systems as well. All current and anticipated weapon systems that utilize mechanical components are expected to benefit from activities conducted in the MDF.

Turbine and Structural Seals Facilities, Glenn Research Center

The Turbine and Structural Seals Facilities (TSSF) consists of two laboratories. The Turbine Seals Laboratory (TSL) includes a high-speed/high-temperature turbine seal rig and an active clearance control test rig. The Structural Seals Laboratory (SSL) includes a hot compression test rig, a hot scrub test rig, a room-temperature flow and scrub test rig, room-temperature flow and permeability test fixtures, and an acoustic seal test stand.

The primary goal of structural seals efforts is to develop unique seals for extreme-temperature engines, hypersonic vehicle airframes, and rocket applications. The primary goal of turbine seals efforts is to develop durable, low-leakage, turbo-machinery seals and approaches to tip clearance for the next generation of subsonic and supersonic engines. The TSSF are used to test innovative seals designs to reduce specific fuel consumption, which can increase the mission time or the load capacity of air-breathing engines. From a DoD perspective, the TSSF provide the test capability to demonstrate how seals perform in the harshest operational environments. The SSL is capable of testing seal compression and durability performance at high temperatures as well as measuring seal leakage over many flow ranges. The turbine seal rig is capable of testing large diameter seals, at high inlet air temperatures, at high speeds and high pressure differentials. It also has the capability to measure high temperature clearances, seal/rotor interface temperatures, seal torque and power loss, leakage rates, and both inlet and exit temperatures and pressures. The active clearance control rig can test large-diameter active clearance concepts, seals, actuators, and clearance sensors under simulated high engine temperatures and pressures. It can also measure high-temperature clearances, actuation rates, and leakage rates, as well as both inlet and exit temperatures and pressures.

The SSL's ability to test seal compression and durability performance at high temperatures is unique, as is its ability to test the contact interaction between seals and ceramic matrix composite structures. The TSL has the nation's only rig that is capable of assessing high-temperature active clearance control schemes and probes under engine simulated temperatures and pressures.

There are no known alternatives to the SSL and the active clearance control test rig. There are also no known alternatives to the TSL that have the speed, temperature, and pressure capabilities required for advanced gas turbine engines. If the TSSF were unavailable, DoD would need to rely on industry facilities, which only have the capability to test to lesser speed, temperature, and pressure combinations. While the individual capabilities of each test rig might be available at another facility, it would require multiple locations to duplicate the full physical capability of the TSSF. The cost and the complexity of coordination would increase if multiple facilities were used. Another alternative would be for the DoD to construct new facilities. However, it would cost several million dollars to do so; and progress on critical programs would be delayed by a minimum of two years.

The TSSF are critical to the defense mission because they are the only facilities in the United States capable of assessing seal compression and durability to sufficiently high temperatures for testing hypersonic vehicle and engine seals, re-entry vehicle seals, and thermal barriers for solid rocket motors. They are the only facilities in the United States capable of testing the high temperatures and speeds expected in advanced gas turbine engines, as well as assessing high-temperature, active clearance control schemes under engine-simulated temperatures and pressures. Since engine manufacturers are not likely to assume the risk of initial testing of innovative seals or clearance control concepts in their engines, validation of innovative seal designs would not be possible without the TSSF.

Impact Dynamics Research Facility (IDRF), Langley Research Center

The Impact Dynamics Research Facility (IDRF) is a 200-foot tall gantry structure that is 400 feet long. In its current state, the structure has a maximum lift capacity of 30,000 pounds, although proposed modifications would increase that capacity to 100,000 pounds.

The IDRF is used for impact (crash) testing of both rotary and fixed-wing vehicles, vertical drop testing of fuselage sections and other aircraft components, tethered-hover testing of vertical/short take-off and landing aircraft, pendulum-swing testing for wire strike protection system validation on military helicopters, impact testing of robotic vehicles, and validation testing of cockpit airbags and external fuel tanks. The facility has helped the DoD and defense contractors gain a better understanding of the fundamentals of crashworthy design, structural impact dynamics, and associated modeling and simulation techniques. The resulting safety enhancements have saved lives, reduced injury levels, and protected valuable equipment and material.

The IDRF is uniquely suited to perform full-scale crash testing of light aircraft and helicopters, under a combination of vertical and forward velocity conditions, onto multiple types of terrain. It is a unique facility, worldwide, for the conduct of pendulum-swing impact tests of full-scale aircraft and rotorcraft. It is equipped with state-of-the-art data acquisition systems and a full complement of anthropomorphic test dummies capable of simulating human occupant response to crash impacts.

The only other facility in the United States capable of conducting crash tests in which both forward and vertical velocity is applied to the test article is at Yuma Proving Grounds in Arizona. However, the facility at Yuma simply uses a crane and does not have the capability to control the orientation of the test article at impact. Additionally, the instrumentation at Yuma is less capable than the instrumentation at the IDRF. Vertical drop facilities are available at Langley Research Center and the Federal Aviation Administration's William J. Hughes Technical Center (Atlantic City, New Jersey); however, they do not provide realistic crash conditions because crashes at those facilities do not involve forward velocities.

Outside the United States, the Laboratory for Impact Testing on Aerospace Structures (LISA), which is located in Italy, is similar to the IDRF. However, it is only half as tall as the IDRF; it can only handle test articles weighing up to 44,000 pounds; and it is not capable of wire-strike testing. Additionally, issues of information security and the willingness of U.S. airframe manufacturers to test proprietary hardware at a foreign facility limit the amount of impact testing that can be performed outside the United States.

Without the IDRF, crash safety technology would suffer since analytical predictions are inadequate substitutes for impact testing. Since the IDRF is the only facility capable of crash testing large rotorcraft, it is critical to the DoD mission. Loss of the IDRF would force DoD to use less capable facilities, resulting in less comprehensive results, unaffordable costs, and/or unacceptable risks to program security.

Wallops Open Air Range, Wallops Flight Facility

The NASA Wallops Flight Facility (WFF) Open Air Range is located off the Virginia Cape, with access to the Mid-Atlantic Test Range warning area. This facility provides a number of test support services, and it is used by the Department of Defense (DoD) to support tests of Navy aviation programs that are conducted from the Patuxent River complex.

In partnership with the Naval Surface Combat Systems Center, Wallops Island, VA, the WFF provides full range support, including range services, tracking radars, launch facilities, target services, and extended down-range potential. This partnership results in competitive program costs through the sharing of Navy and NASA assets and expertise.

The WFF Range Control Center fully supports sub-orbital, orbital, aeronautical, and recovery operations for the Wallops Test Range and remote operations. The WFF range provides fixed and mobile tracking radars as well as surveillance radars to detect water surface and airborne targets, metric tracking capabilities, fixed and mobile range telemetry facilities, as well as command uplink capabilities. Other WFF capabilities include radio frequency communications receiving, frequency monitoring, and interference control equipment, as well as the master timing station. The Communications Transmitter Facility supports all local range safety requirements for command, destruct, and remote command destruct capability. The optical and TV capabilities at Wallops include still, video, and motion picture photography.

Because of the VACAPES offshore warning areas, the Wallops Open Air Range is relevant to almost every naval aviation research and system development flight test asset—past, present, and future. The Wallops Open Air Range is the only available facility with access to the Mid-Atlantic Test Range warning area, thus making it possible to achieve virtually unrestricted airspace. If this facility were to close, a dedicated DoD capability could be created by purchasing the instrumentation currently provided by WFF and relocating it, or purchasing/leasing from another source. The performance of the procured instrumentation would be similar (or even better), but the long-term cost to procure and maintain the instrumentation and expertise would be higher than the use of shared assets and personnel.

Other flight test centers like those at Edwards, Eglin, or Point Mugu could be used—with Point Mugu being the most likely candidate due to its similar offshore conditions. Most of the necessary instrumentation may be available at those sites; but it is likely that some additional or different instrumentation may be required, which would increase costs. A limitation of other centers is that their use of the electromagnetic spectrum for various sensors is constrained by other users of that spectrum. The WFF is able to use much more of the spectrum, which results in better test data. Additionally, the other flight test centers are substantially further from the Patuxent River complex. Thus, their use would result in more difficult coordination and higher test costs if testing was performed at multiple locations.

Without the critical support that NASA provides at the Wallops Open Air Range, the Navy would not be able to execute its aviation program workload from the Patuxent River complex. Virtually every Naval Air Systems Command program and platform that uses the VACAPES offshore warning areas relies on some type of instrumentation support that emanates from Wallops—including radar, global positioning system (GPS), telemetry, and communications support. The data gathered by the range instrumentation sensors is brought back to Patuxent River via a Navy-owned communications network and displayed in the control room or at project engineering workstations.

National Full-Scale Aerodynamics Complex (NFAC), Ames Research Center

The National Full-Scale Aerodynamics Complex (NFAC) was mothballed by NASA in FY2004, and it is now being reactivated by the Air Force under a lease arrangement from NASA. The NFAC is used for full-scale rotorcraft, aerodynamic force and moment, inlet performance, drag performance, stability and control, powered engine simulation, jet effects, propulsion integration, acoustics, parachute performance, high angle-of-attack, and other types of testing in the subsonic flight regime.

The NFAC is the world's largest wind tunnel and includes two test sections. The 40- by 80-foot test section is capable of routinely providing a continuous flow at speeds ranging from 0 to 250 knots, while the 80- by 120-ft test section is capable of providing continuous flow at speeds ranging from 0 to 80 knots. Speeds of 300 and 100 knots respectively could be achieved for a short time if necessary. The acoustically treated test sections allow testing rotorcraft and other test articles in low acoustic background environments. Each test section has a large turntable and a 6-component floating frame external balance that can accommodate a variety of struts to achieve desired angles-of-attack and sideslip. Compressed air is available to drive engine simulators, ejectors, and plume simulation tests. Rotorcraft test beds are available to support testing of advanced rotor blade concepts. The size of the facility allows full-scale aircraft to be used as test articles, including operational aircraft.

In the recent past, the NFAC has been used by DoD for the wide chord blade individual blade control (IBC) program, as well as for V-22 Osprey performance, vortex ring assessment, unsteady aero, and noise reduction testing. The NFAC has also been used to support the V-22, Joint Strike Fighter, and advanced low observables platform programs. NASA and DoD have invested significant resources to develop the Large Rotor Test Apparatus (LRTA) to accommodate large rotors in the NFAC.

Today, during NFAC re-activation, the DoD is preparing to test its LRTA IBC program, which was delayed by NFAC closure. Other planned activity includes the Smart Material Active Rotor Technology On-blade Control Program; the Active Elevon Rotor Program; and the Heliplane Program. Other future testing being discussed includes the Slowed Rotor Heliplane, Refueling Drogue, Navy UH-1Y Blade Fold Programs; and the Air Force AMC-X Program. Other potential DoD test programs include testing for the V-22 as well as exploratory and demonstration testing for the Joint Heavy Lift concept development.

The NFAC's 80- by 120-ft test section is unique because of its size and velocity. There is no viable alternative when this size is required. Smaller U.S. wind tunnels such as the Transonic Dynamics Tunnel, the 14- by 22-ft wind tunnel, and the 30- by 60-ft wind tunnel at NASA Langley Research Center; the Lockheed Martin 16- by 23-ft tunnel; and the Boeing 20-ft tunnel have similar speed ranges. Each, however, has size/scale limitations that would significantly impact data fidelity or preclude the use of actual flight hardware. These limitations include physical size phenomena (such as rotorcraft dynamics, propeller effects, and aeroelastic structural dynamics) and scaling impacts (the combination of stiffness, mass distribution, transport time, and viscous effects). Without the NFAC, rotary wing vehicle research, development, test, and evaluation will be limited to using small-scale wind tunnel testing and flight testing to support both advanced aeromechanics technology and advanced concept and system development. Further, use of down-sized models cannot produce the required physical responses, which will result in unacceptable risk to the test program.

Overseas alternatives include the 20- by 26-ft German-Dutch Large Low Speed Wind Tunnel (DNW) in The Netherlands, and the Russian TsAGI T-101 tunnel at the Zhukovsky Airbase in Moscow, Russia. The DNW tunnel can be configured as either a 26- by 20-ft tunnel at 225 knots, which is comparable to the speed in the 40- by 80-ft tunnel, or a 31- by 31-ft tunnel at 175 knots, which is slightly slower than the 40- by 80-ft tunnel. While the DNW tunnel has excellent acoustic test capability and is a modern facility, because of the substantially smaller size and slower speeds, the DNW is a poor alternative to the NFAC 40- by 80-ft test section. The TsAGI T-101 tunnel has a maximum speed of 107 knots, which is less than half the speed range of the 40- by 80-ft test section, and is about half the size of the 80- by 120-ft. Flow exits the elliptical nozzle into a large open test section, which diminishes the flow quality. While the overall size is comparable to the 40- by 80-ft tunnel, the T-101 tunnel and its systems are old, acoustical treatment is an issue, and uniform flow quality is less. The T-101 is the first alternative for its size and comparable speed with the NFAC tunnels, but should be avoided because it can only test at a smaller scale and would have problems similar to those of smaller facilities discussed above. Finally, security is a potential risk and should be evaluated based on the security requirements for the test program.

The NFAC saves time and money by permitting evaluation of full-scale rotorcraft at flight conditions, without the need for flight testing. Loss of this capability would result in greater effort to achieve the same objectives in rotorcraft system development, and rotorcraft S&T efforts would be severely impacted. State-of-the-art modeling and simulation lacks the fidelity required for design validation of conventional helicopter rotors or for advanced rotor technology (such as IBC, on-blade active flaps, or multiple on-blade active flaps). The NFAC enables the DoD to validate and improve modeling and simulation tools currently being developed. Loss of the NFAC would impact the readiness level of the technology and the ability to analytically model future designs, ultimately slowing the entire development process.

Loss of the NFAC would also have major impacts on future S&T testing in support of new, large-scale rotorcraft—such as JHL. Large rotor development will have scaling issues for viscous flow and aeroelastic structural dynamics, as well as design requirements that will demand large-scale testing to demonstrate acceptable risk reduction. Testing in smaller-scale facilities would result in the potential to miss technical issues in the full-size system. Planned large-scale testing includes proof-of-concept testing of emerging new concepts; risk reduction and development testing for new aircraft; and accurate, "no-excuses" experimental data on real-world hardware needed to validate modeling and simulation tools.

References

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[3] Philip S. Anton, Dana J. Johnson, Michael Block, Michael Brown, Jeffrey Drezner, James Dryden, Eugene C. Gritton, Tom Hamilton, Thor Hogan, Richard Mesic, Deborah Peetz, Raj Raman, Paul Steinberg, Joe Strong, and William Trimble, "Wind Tunnel and Propulsion Test Facilities, Supporting Analyses to an Assessment of NASA's Capabilities to Serve National Needs" RAND Corporation, TR-134, 2004.

Appendix A. Abbreviations and Acronyms

AEDC	Arnold Engineering Development Center
APTU	Aerodynamic Propulsion Test Unit
ARA	Aircraft Research Association
ARES	Affordable Responsive Space
ARH	Army Reconnaissance Helicopter
BRAIT	Boeing Research Aerodynamic and Icing Tunnel
CAV	Common Aero Vehicle
CFD	computational fluid dynamics
CIRA	Italian Aerospace Research Center
CMF	Cockpit Motion Facility
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director of Defense Research and Engineering
DoD	Department of Defense
DNW	German-Dutch Wind Tunnels
DOF	degrees of freedom
ETW	European Transonic Wind Tunnel
GFORCE	Generic Fighter Operations Research Cockpit Environment
GPS	global positioning system
HCV	Hypersonic Cruise Vehicle
HDF	Helicopter Drives Facility
HTF	Hypersonic Tunnel Facility
HTT	High Temperature Tunnel
IBC	individual blade control
ICAB	Interchangeable Cab
IDA	Institute for Defense Analyses
IDRF	Impact Dynamics Research Facility
IRT	Icing Research Tunnel
IWT	Icing Wind Tunnel
JHL	Joint Heavy Lift
JML	Joint Medium Lift
JSF	Joint Strike Fighter

LAMP	Large-Amplitude-Multi-Purpose
LISA	Laboratory for Impact Testing on Aerospace Structures
LRTA	Large Rotor Test Apparatus
LUH	Light Utility Helicopter
M	Mach number
M&S	modeling and simulation
MDA	Missile Defense Agency
MDF	Mechanical Drives Facility
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act
NTF	National Transonic Facility
RPM	Revolutions Per Minute
S&T	science and technology
SED	Single Engine Demonstrator
SMART	Smart Material Active Rotor Technology
SSL	Structural Seals Laboratory
TDT	Transonic Dynamics Tunnel
TRMC	Test Resource Management Center
TsAGI	Central Aerohydrodynamic Institute (Russian)
TSL	Turbine Seals Laboratory
TSSF	Turbine and Structural Seals Facilities
UAV	unmanned aerial vehicle
UCAV	unmanned combat aerial vehicle
USD(AT&L)	Under Secretary of Defense (Acquisition, Technology and Logistics)
VACAPES	Virginia Capes
VLAB	Virtual Laboratory
VMS	Vertical Motion Simulator
VST	Vertical Spin Tunnel
VWT	Vertical Wind Tunnel
WFF	Wallops Flight Facility